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THE NAVY'S PLANS FOR DESIGN SAFETY OF FUZES

10 JULY 1967

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 67-115

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THE NAVY'S PLANS FOR DESIGN SAFETY OF FUZES

Prepared by:
Allen M. Corbin

ABSTRACT: An ad hoc group met during 1965 to review the Navy's guidelines for fuze safety which had remained unchanged since issue in 1953. This group recommended that modifications and additions be adopted. Many of the modifications and additions were based on the similarity of problems in obtaining safety and reliability. Designers need safety objectives comparable to design objectives for reliability. The safety hazards analysis is proposed as a method to increase the engineering value of safety design objectives. The relation between redundancy for reliability and redundancy for safety is discussed. The safety analysis is safety's equivalent of reliability's failure modes and effects analysis.

The fuze safety design program which is developing from the ad hoc group recommendations will show marked similarity to present day reliability programs. Because there is much unfinished work the full potential of this program will not be realized for about two years.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 67-115 10 July 1967

THE NAVY"S PLANS FOR DESIGN SAFETY OF FUZES

This report describes the fuze safety design program being developed as the result of recommendations of an ad hoc group with representation from the Naval Ordnance Laboratory, White Oak (NOL(WO)), the Naval Weapons Center Corona Laboratories, Corona, and the Naval Weapons Laboratory, Dahlgren. The material in this report was first presented as a talk by the author. Work on this program in NOL(WO) is being performed under Task A05 532 063/S470 BO 02.

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By direction

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ILLUSTRATIONS

REFERENCES

(a) BUORD ltr Re2b-JJSD:bjn S78-1(26) Ser 58079 of 8 Jun 1953 to NOL(WO)
(b) BUWEPS ltr RMMO-211:PC of 3 Dec 1964 to NOL(WO), NOL Corona, and NWL, Dahlgren
(c) NOL(WO) ltr NO:AMC:mc 8010 Ser 7855 of 30 Dec 1965 to BUWEPS (RMMO)
(d) MIL-STD-721A Definitions of Terms for Reliability Engineering
(e) NOLC Report 666, Experimental Methods for Determining the Effectiveness of Interruption of a Fuze Explosive Train

INTRODUCTION

1. In 1953 the Bureau of Ordnance issued a statement of Basic Safety and Arming Objectives for U. S. Navy Fuzes. For many years this document, reference (a), set the standards for Navy fuze safety. Reference (b) dated 3 December 1964 requested that the provisions of reference (a) be reviewed and reevaluated in the light of technical advances and modern weapon trends to determine whether or not these criteria were adequate or needed to be changed. The ad hoc group, established by reference (b) to conduct the study, met seven times in 1965 and issued a summary report which was forwarded to the Bureau of Naval Weapons by reference (c). In this report the ad hoc group recommended a number of additions and changes to existing guidance for fuze safety. These recommendations were accepted and the work involved in preparing material to put these recommendations into effect is in progress. In this report a concise picture of the program for design safety of fuzes and the reasoning behind the program approach are given.

SAFETY AND RELIABILITY

2. Safety and reliability have long been associated terms, but there has appeared to be a growing disparity in the means employed to obtain excellence in these two qualities. Formal reliability programs have been adopted as a necessary and valuable part of weapon and weapon component developments. Various techniques and analyses have been developed to guide product designs toward high reliability. But safety has appeared to be accepted as a by-product of reliability programs rather than a quality demanding its own improvement techniques. The guidelines for safety including rules of thumb, expert opinions, and standard tests had changed very little while reliability guidelines were making marked advances. In its deliberations, the ad hoc group pondered these problems. One conclusion reached was that it is possible to enhance safety through techniques very similar to those used for reliability. With continued thought, the reasons for this have become clearer. They are presented here because they are vital to the program which is being developed for design safety of fuzes.

3. The comparison of safety and reliability must start with the definitions. One of the contributions of the great interest in reliability of the last decade was agreement on definitions of commonly used terms. Reference (d) defines terms for reliability engineering. It defines reliability as:

> The probability that material will perform its intended function for a specified period under stated conditions.

The important aspects of this definition are that reliability is a number and is therefore on a measurable scale, and the number is valid under stated conditions for a specified period. For a weapon the

important conditions are those existing during preparation for launch, launch, and flight to target. This is when performance is required. The conditions existing before launch, such as in handling, transportation, and storage, cannot be ignored. But these are not operating conditions and the important thing is that these conditions not destroy the capability of working in the launch conditions. These logistic conditions are like the trip an athlete must take to run a race in another city. The trip must not exhaust him so much that he can't run. The medal he may win is for performance in the race.

4. In standardization of terms safety is far behind reliability. No single accepted definition of safety exists. It was therefore necessary to define safety in terms comparable to those used in reliability. Unsafety, rather than safety, was defined in order to be in agreement with the tendency to think in terms of a safety failure rate. The proposed definition of unsafety is:

> The probability of experiencing the destructive forces of one's own weapon resulting from any conditions before intended launch and safe separation.

There are two important aspects of this definition. First, unsafety is a number and is therefore on a measurable scale. This point is only academic. Measuring unsafety may not be practical. Second, there is not any single set of conditions in which the number is valid. There are many sets of conditions, in fact, any conditions before intended launch and safe separation. This means anything that can happen in handling transportation, storage, and launch.

5. The ability to measure reliability has as little to do with obtaining it as taste of a good cake has to do with mixing and baking it. Reliability is obtained by the application of sound engineering and management techniques and methods. Measurement is simply an index of the relative success or failure of these. The inability to measure unsafety does not preclude the application of sound engineering and management techniques to obtain good safety. If anything, it stresses the need. The problem was to determine what these techniques should be.

6. In order to design for high reliability the designer needs a lot of information. To illustrate this Figure 1 shows a small part of what he needs to know. He needs to know what the normal environments will be. For example, if in the design of his component he chose materials which were only good to 200 degrees Fahrenheit and in flight his component failed because temperature actually reached 400 degrees, the unreliability would be the result of his lacking needed information. If weapon launch involved closing two switches in proper order and these switches were easily confused resulting in aborted missions, the unreliability would be the result of inadequate attention to human engineering. Is it logical to assume that a designer needs less information to design properly for safety? It is not. The designer needs reasonable estimates of the abnormal environments which may occur in accidents or incidents in handling, transportation, storage, and

during launch. He needs guidance in the careless or thoughtless acts of handling or operating personnel so he can think of ways to protect them from their own carelessness. Other people have thought that this kind of information was needed too. Jolt, jumble, and forty foot drop represent abnormal environments which every fuze designer respects. But these do not go far enough. They only represent a few of the abnormal things that can happen.

7. In an attempt to increase information available to the designer regarding abnormal environments and personnel actions, a procedure called "hazards analysis" is being developed. The "hazards analysis" is really nothing more than a step by step, systematic procedure for considering the maximum number of abnormal events which can occur in the phases of weapon life before launch to safe separation. Figure 2 shows the common phases of assembly, handling, transportation, storage, and launch. Opposite each phase are listed some of the more important hazardous events which can occur during the phase. During assembly parts can be left out or assembled wrong. Probably an inspector is supposed to catch these things, but an ingenious designer might devise ways that the device would not go together if critical parts were omitted. Rough handling and drops are rather common in ammunition handling. Jolt, jumble, and forty foot drop tests insure that fuzes are built to take a lot of rough handling. But these alone don't cover all possibilities. A particular weapon may have special handling gear which may produce special situations if it fails. In transportation there is always the chance of collision, overturning, and fire. And, as shown in Figure 2, unusual things can happen during storage and launch as well.

8. The purpose of the hazards analysis is to express these life cycle hazards in terms which the designer can use. Shock, for example, would be expressed in terms of a velocity change, or the probable ranges of gravity units and time. The magnitudes would be those estimated to be possible or probable in the accidents being considered. Then the designer's problem is to arrive at a design solution which assures weapon safety in the environment. Figure 3 illustrates this. The rectangles on the left represent the accident environments or personnel actions. The circles on the right represent design solutions. In other words, the circles are safety devices which, in theory, will give protection. One device is likely to be adequate protection for a good many of the accident events listed. But it is not likely to have the proper characteristics to give protection in all accidents. So when an environment or action appears for which the first device is not suitable, a second device is added to the system. This process is continued until the design solution can protect against all the accident events. Some of the devices added will provide additional protection in events already covered by other devices. This double or triple protection is illustrated by the dashed lines.

9. If this process is done thoroughly it produces a list of environments applicable to safety. It gives the designer the safety equivalent of the normal environments which he needs in order to design for reliability. The nature of the data will be quite different. The safety environments will not be predicted as accurately because

accidents are less predictable than normal events. At best, the levels of environments will be rough estimates. But for safety design, often this is all that is needed. For example, the designer may find an acceptable solution regardless of whether the peak accident shock is 1000g or 10,000g. The process also lists dangerous personnel actions. The solutions for these may be through design. This is human engineering for safety. Or the solutions may be precautions and restrictions, which takes them out of the designers hands. What is best depends on the weapon and the circumstances in which it will be used.

10. If the design solution for safety coming out of the hazards analysis calls for more than one safety component, this is redundancy for safety. This is another area where the techniques for reliability and safety are so similar. Figure 4 shows a block diagram or reliability model of a weapon. When called upon to operate, components a, b, c, either d, e, 1, and 2 must function. Redundancy is employed in component d. The purpose of this redundancy is to increase the probability of operation. So it is assumed that component d was considered to be a weak link. Its failure rate was too high and to compensate for this another component was put in parallel with it. If the high failure rate of d was the direct result of one of the normal environments, it would do little good to put another identical component in parallel with it. The second component would be caused to fail by the same environment. However, it is unlikely that a component which could not survive one of the normal environments would get into the system. So redundancy for reliability is usually used to compensate for random unpredictable failures. In other words, a certain number of component d's are "lemons". By placing a second component d in parallel with the first, operation will stop at this component only if both components happen to be "lemons".

11. In Figure 4, components 1 and 2 are safety components. The fact that two are shown is redundancy for safety. Note that safety redundancy is series whereas reliability redundancy is parallel. The reason for this is quite simple. In reliability the purpose of redundancy is to enhance operation. So an alternate operating path is provided. In safety the purpose of redundancy is to decrease the chance of premature operation. This is done by adding another series barrier.

12. The redundant safety components are usually different. There is good reason for this too. It was mentioned above that redundancy for reliability is usually to compensate for "lemons" and not for normal environment caused failures. "Lemons" may occur in safety components too but this is not as big a problem as failures caused by the accident environments. Therefore the same reasoning applies. As long as the failures are environment induced, identical redundancy is not the correct solution. The same environment would defeat both of two identical devices. The solution is dissimilar redundancy in which the different safety components are selected so that no one environment will defeat all devices. This is the common solution for safety because accident environments are numerous and can be very severe.

13. The brief discussion of similarities in designing for safety and reliability was presented because this is really the backbone of the design safety program recommended by the ad hoc group. The remainder of this report will be devoted to discussion of the recommendations and the status of supporting material which is to be prepared.

AD HOC GROUP RECOMMENDATIONS

14. Figure 5 shows seven areas which were the subject of recommendations of the group. These seven will be mentioned briefly and then each will be discussed in more detail. First, the group felt that there were requirements and objectives applicable to all fuzes. These are much like the Basic Safety and Arming Design Objectives for U.S. Navy Fuzes issued in 1953. It was intended that these would be stated as part of the safety policy for fuzes. The second recommendation dealt with explosives sensitivity. The Navy has long used a rule that no explosive more sensitive than tetryl should be used beyond the explosive train interrupter. This rule is becoming more and more of a problem because many new explosives are being developed and it is difficult to say what is or isn't more sensitive than tetryl. A series of eight sensitivity tests to determine acceptable explosives sensitivity was recommended. The third recommendation is to use a more complete test procedure in determining detonator safety. The fourth recommendation anticipates the possible use of exploding bridge wire devices in fuzes. These fuzes probably would not have interrupted explosive trains. In such cases there is need for more electrical switching safety than has been used in existing electric fuzes. The safety hazards analysis is the fifth recommendation and it was discussed in some detail earlier. Its purpose is to develop safety design objectives stated in terms which the designer can understand and use. The sixth recommendation was that hardware be studied in a safety analysis. This is really safety's equivalent of reliability's Failure Modes and Effects Analysis. The seventh recommendation was to write a report discussing weapon safety concepts. It is hoped that this can serve as a text book on design safety.

15. Figure 6 lists the requirements and objectives applicable to all fuzes. These include statements on explosive train interruption, explosives sensitivity, in-line explosive trains, safe arm indication, a safety failure rate, stored energy for arming, a minimum of two series arming mechanisms, and use of a post-launch environment. Explosive train interruption is required when the fuze contains sensitive explosives. Sensitive explosives are those which are too sensitive in any one of the eight criteria tests. The effectiveness of interruption is to be determined by the methods described in the report which was the third recommendation of the group. In-line explosive trains are not prohibited but, if used, must employ explosives of acceptable sensitivity. This probably means exploding bridge wire initiation, and a report will be prepared describing special switching precautions to control the electric energy of the firing unit. Safe-arm indication is a requirement for fuzes which can be armed by personnel during handling of the fuze or fuzed weapon.

Objectives were set apart from requirements because it was recognized that in some cases it would not be feasible to comply with the objectives.

16. Acceptable explosives sensitivity is to be determined by eight sensitivity tests. The eight tests are:

(1) Small Scale Gap Test

(2) Impact Sensitivity Test

(3) Impact Vulnerability (Flying Plate Test)

(4) Vacuum Stability Test

(5) Hot Wire Ignition Test

(6) Bonfire Test

(7) Electrostatic Sensitivity Test

(8) Friction Sensitivity Test

A Weapons Requirement (WR) will be issued with a title reading something like this:

"Sensitivity Criteria for the Qualification and Control of Booster and Lead Explosives".

The procedure for running each test and the equipment to be used will be specified. Each test will have a pass-fail criteria. The sensitivity of the explosive will be acceptable only if it satisfies the criteria of all eight tests. When this WR is issued it will allow an explosive to be judged on its own merits rather than requiring comparison to tetryl.

17. The effectiveness of explosive train interruption will be determined by more thorough methods than are now required by the Static Detonator Safety Test, (MIL-STD-331, Test 115). The method will determine how much design margin exists in the barriers which prevent accidental initiation from fixed detonator to slider (or rotor) detonator to lead, fixed detonator to lead, fixed detonator to booster, and fixed detonator to main charge. The report of these methods is the only one of the supporting documents which has been completed. It is reference (e).

18. The safety program recommended will not exclude in-line electro-explosive devices (EED's). It will however, insure that such devices do not exceed the explosive sensitivity limits and that there is safety in the control of the electrical energy which compensates for the lack of explosive train interruption.

19. The hazards analysis was discussed in paragraphs 7, 8, and 9. Its purpose is to increase completeness of safety design objectives.

One problem not mentioned previously, is that accident environments occur only occasionally. Some types of accidents occur more frequently than others. The more frequent accidents deserve more safety design consideration than infrequent ones. The Air Force uses the term "credible accident environments". No line has yet been drawn between "credible" and "incredible". It is still a matter of judgment. The hazards analysis should list credible accident environments with judgments of credibility made far enough in advance so that the designer has firm goals.

20. Procedures for conducting a safety analysis were published in 1955 in NAVORD Report 4135, entitled Relative Accident Probability (RAP) Analysis. It was recommended that this report be revised to make it more useful and also more available, since it is out of print. The Air Force developed a safety analysis quite similar to the RAP Analysis in basic approach. It is called Fault Tree Analysis. Either one of these analyses is the safety equivalent of reliability's Failure Modes and Effects Analysis (FMEA). The following distinction is made between a safety analysis and a hazards analysis. A safety analysis is a study of actual hardware in accident situations. It is therefore a part of safety evaluation. A hazards analysis is a study of environments or personnel actions in accident situations. It is conducted to establish important design objectives. Actually the hazards analysis can evolve into a RAP Analysis as the hardware develops. The group recommended use of a safety analysis as a useful tool for safety evaluation.

21. The report on Weapon Safety Concepts is intended to serve as background for design safety engineering. One problem in safety design is that personal experience plays such an important part. Personal experience is extremely valuable. But a good safe design is based on the experiences of many rather than a few individuals. Therefore the purpose of this report is to present ideas to increase the objectivity of designers.

22. Figure 7 gives a concise picture of the fuze safety design program. The rectangles enclosing small circles are documents being prepared to implement the program. The report on Weapon Safety Concepts combined with the designer's experience and ability will give design competency. Complete safety objectives will be obtained from policy requirements and objectives, explosives sensitivity criteria, and the safety hazards analysis. Proof of a safe design will be obtained from explosive train interruption tests, the safety analysis, and other safety tests. The nature of these latter tests will be strongly influenced by the findings of the hazards analysis and the safety analysis.

23. A slightly different program will apply for a fuze without explosive train interruption and with an in-line electroexplosive device (EED). In this case the report on design guides and test procedures for in-line EED's will contribute to design objectives and test procedures and the report on testing explosive train interruption will not apply. This program is shown in Figure 8.

STATUS

24. As this report is being written, two of the seven documents needed to implement this program are complete. One of these, the statement of policy including requirements and objectives applicable to all fuzes, is an interim publication and will require revision when the supporting documents are complete. It is MIL-STD-1316 (Navy) entitled Fuzes, Navy, Design Safety Criteria For. The second published document is NOLC Report 666, Experimental Methods for Determining the Effectiveness of Interruption of a Fuze Explosive Train. Two reports are nearing completion. These are the report on weapon safety concepts and sensitivity criteria for lead and booster explosives. Both should be complete and in final review by the end of calendar year 1967. The present goal for completing the reports on safety hazards analysis and design guides and test procedures for in-line EED's and for revising the report on safety analysis is July 1968. When all documents are complete MIL-STD-1316 will have to be revised to include them as requirements. Consequently it is likely that the full potential of this program will not be realized for about two years.

FOR A RELIABLE DESIGN:	FOR A SAFE DESIGN:
1. The expected environments of handling, transportation, storage, and launch and flight to target.	1. The abnormal environments of accidents or incidents in handling, transportation, storage, and launch to safe separation.
2. The careless or thoughtless acts of personnel which can result in mission failure and which can be avoided by design.	2. The careless or thoughtless acts of personnel which can result in unsafety and which can be made less hazardous by design.

FIG. 1 SOME THINGS THE DESIGNER MUST KNOW

PHASE	HAZARDOUS EVENTS
Assembly	Personnel errors and carelessness.
Handling	Drops, rough handling, crushing.
Transportation	Collisions, overturning, fire.
Storage	High and low temperatures, extremes of humidity and pressure, effects of disasters such as fire and storm.
Launch	Abnormal launch environments, personnel errors, premature removal of safety features.

FIG. 2 LIFE CYCLE HAZARDS

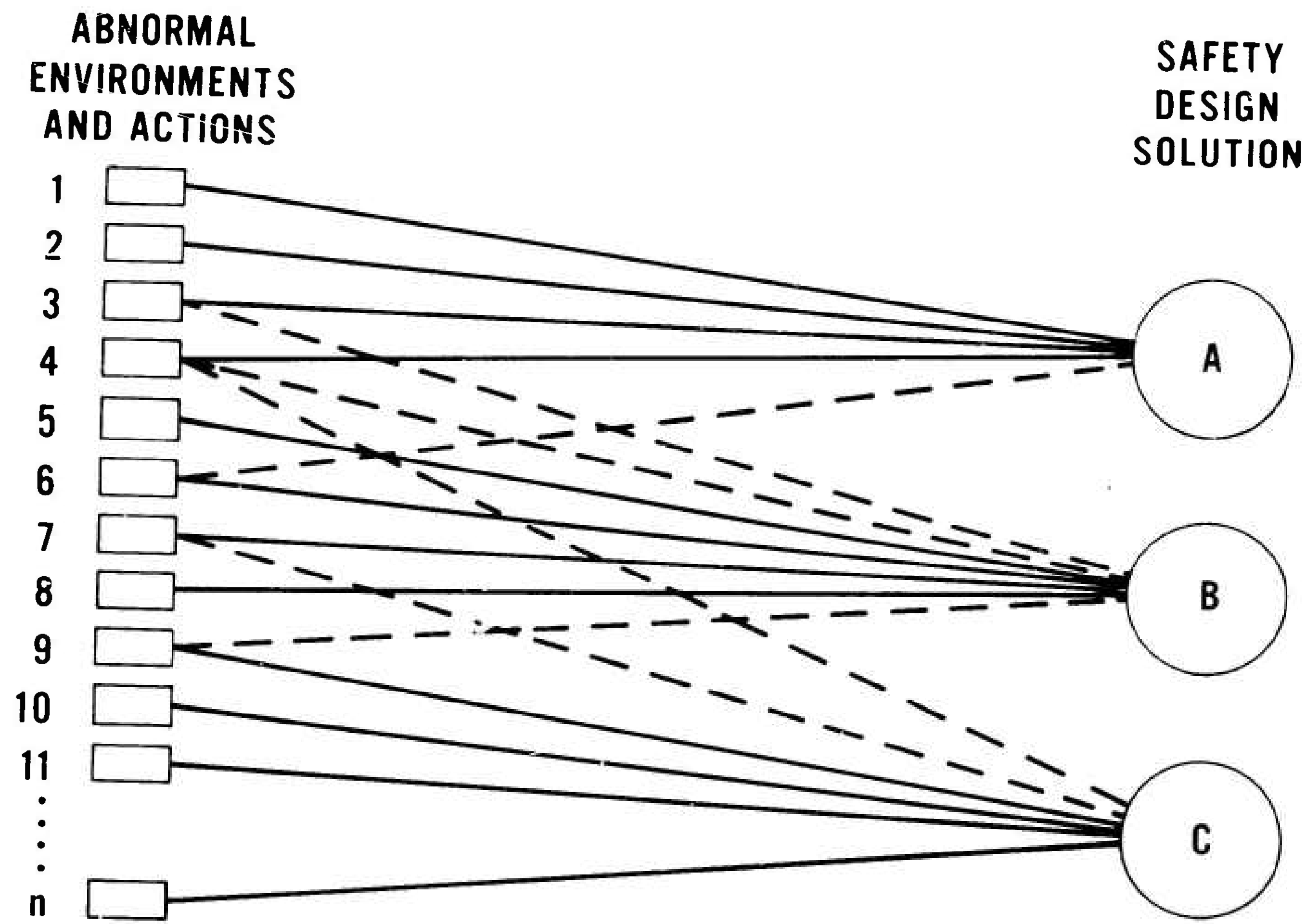

FIG. 3 SAFETY HAZARDS ANALYSIS

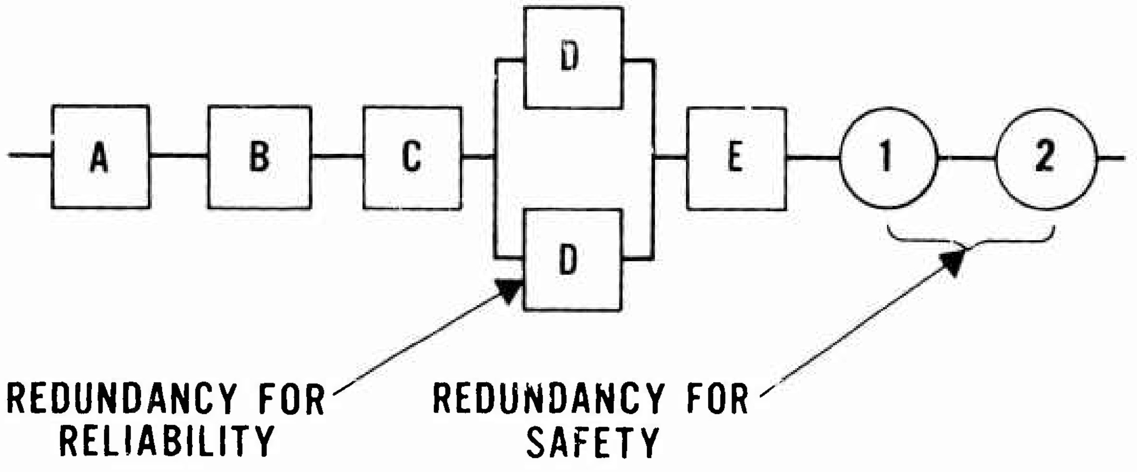

FIG. 4 WEAPON SYSTEM BLOCK DIAGRAM

1. Issue a Fuze Safety Policy which will include requirements and objectives applicable to all fuzes.
2. Prepare tests and criteria to determine acceptability of an explosive for in-line use.
3. Describe test procedures for evaluating effectiveness of explosive train interruption.
4. Prepare design guides and describe test procedures to give adequate control of use of in-line EED's. (EBW devices).
5. Describe procedures for conducting a safety hazards analysis to obtain weapon dependent safety objectives.
6. Revise procedures for conducting a safety analysis of a completed design (based on RAP Analysis or Fault Tree Analysis).
7. Write a report discussing general weapon safety concepts to provide background for safety design.

FIG. 5 AD HOC GROUP RECOMMENDATIONS

The fuze safety policy will include the following requirements and objectives applicable to all fuzes.

REQUIREMENTS:

1. Explosive train interruption where fuze employs sensitive explosives.
2. Sensitivity limit for lead and booster (in-line) explosives set by eight sensitivity tests.
3. Special switching provisions for in-line EED's (EBW devices.)
4. Safe-arm indication for fuzes which could be armed during handling.

OBJECTIVES:

1. A safety failure rate of less than one in one million.
2. Store no energy for arming; obtain energy from a launch environment.
3. Use at least two independent series arming mechanisms.
4. Use a post-launch environment to arm.

FIG. 6 REQUIREMENTS AND OBJECTIVES

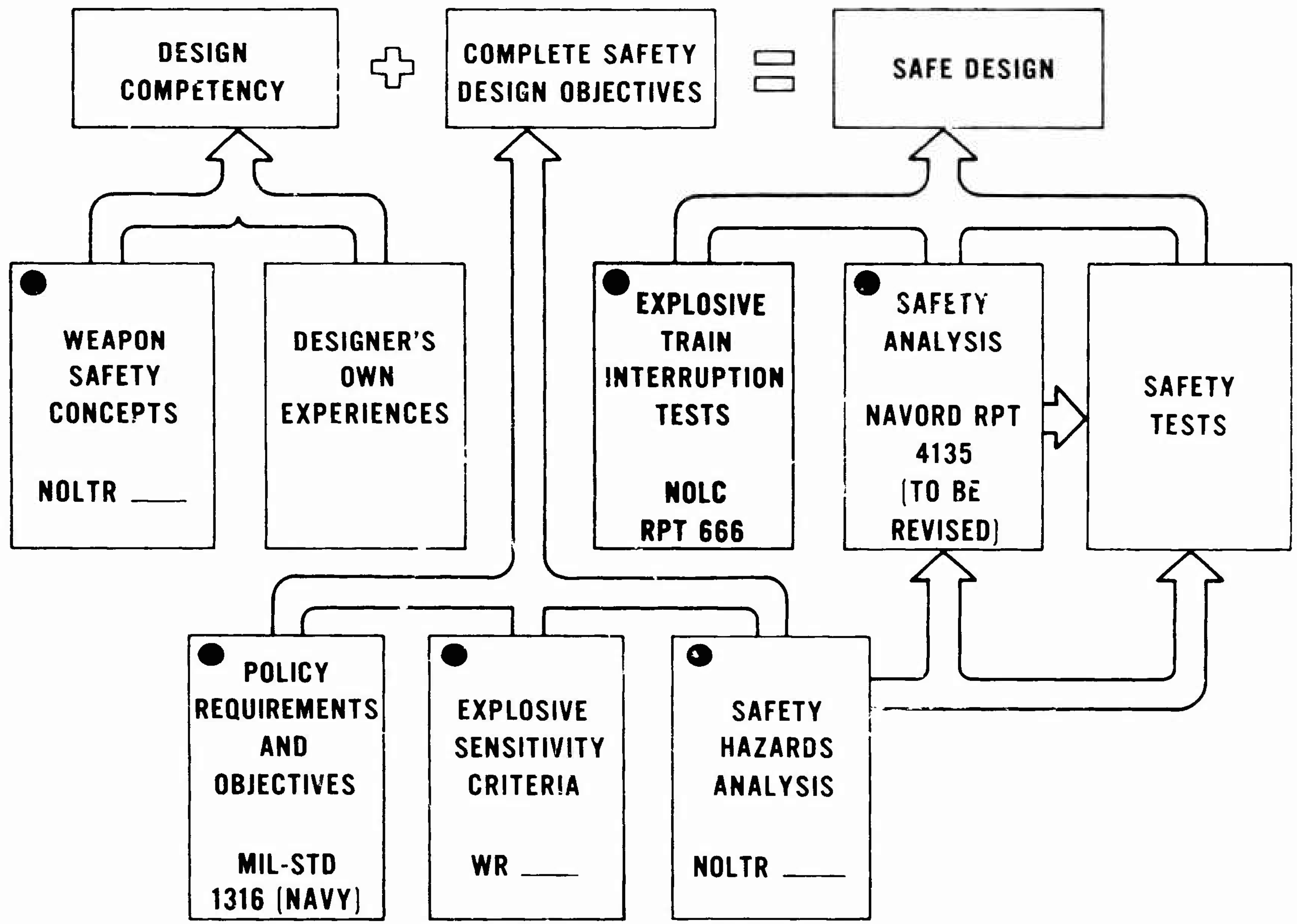

FIG. 7 FUZE SAFETY DESIGN PROGRAM

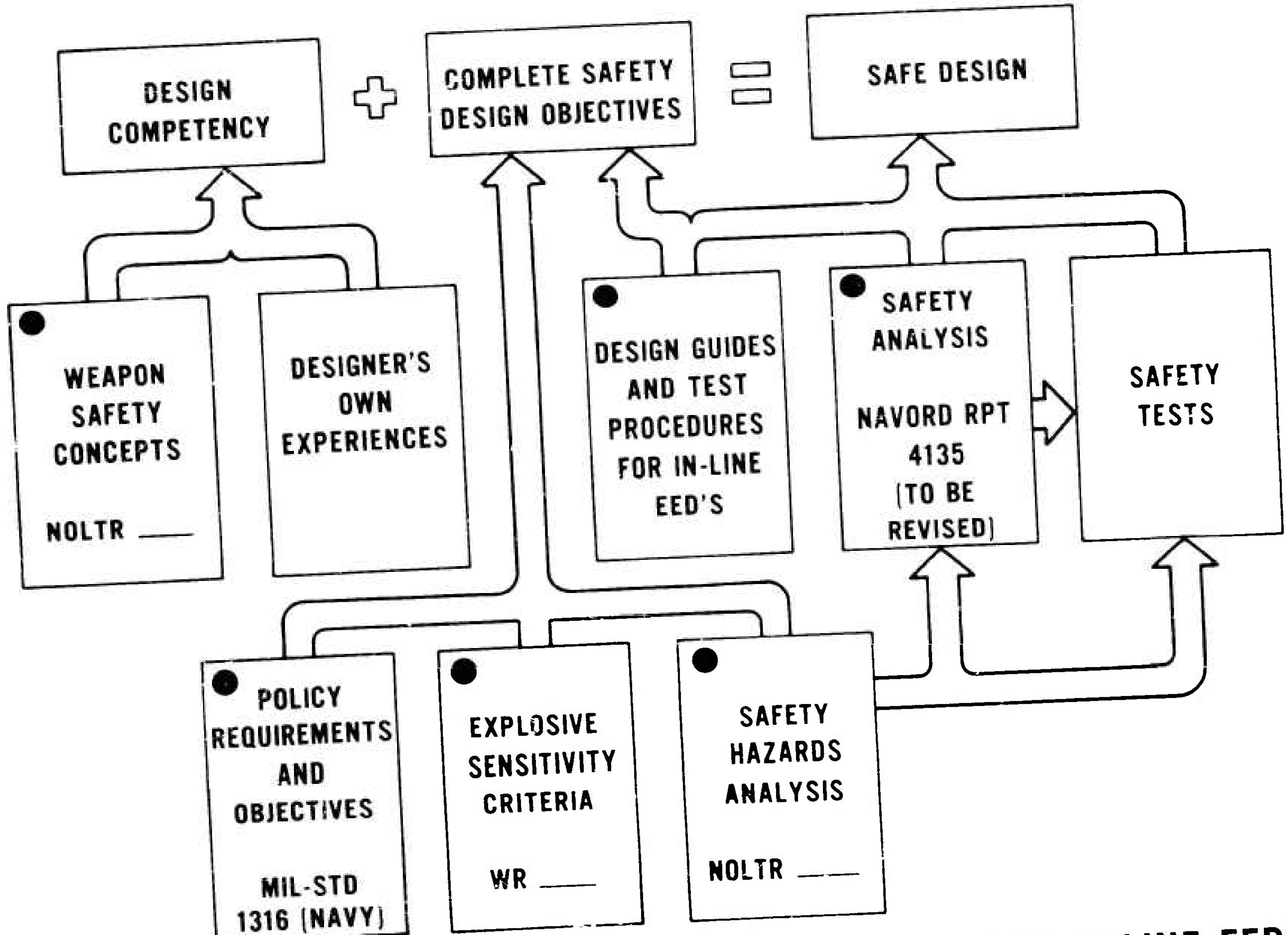

FIG. 8 FUZE SAFETY DESIGN PROGRAM FOR FUZE WITH IN-LINE EED.

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY

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Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 67-115)
THE NAVY'S PLANS FOR DESIGN SAFETY OF FUZES, by Allen M. Corbin. 10 July 1967. 8p. charts, tables. NOSC task AC5 532 C63/S470 BO 02.

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2. Fuzes - Reliability
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I. Title
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SUPPLEMENTARY

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DEFENSE DOCUMENTATION CENTER

NOTICES OF CHANGES IN CLASSIFICATION, DISTRIBUTION, AND AVAILABILITY

TAB No. 69-22 15 November 1969

IDENTIFICATION	FORMER STATEMENT	NEW STATEMENT	AUTHORITY
AD-823 002 Naval Ordnance Lab., White Oak, Md. Rept. no. NOLTR-67-115 10 Jul 67	No Foreign without approval of Naval Ordnance Lab., Attn: Code 730-3, White Oak, Md.	No limitation	USNOL ltr, 4 Sep 69

IDENTIFICATION FORMER STATEMENT NEW STATEMENT AUTHORITY